

University of Dundee

Epicardial Adipose Tissue Is Related to Arterial Stiffness and Inflammation in Patients with Cardiovascular Disease and Type 2 Diabetes

Al-Talabany, Shaween; Mordi, Ify; Houston, J. Graeme; Colhoun, Helen M.; Weir-McCall, Jonathan R.; Matthew, Shona Z.

Published in:
BMC Cardiovascular Disorders

DOI:
[10.1186/s12872-018-0770-z](https://doi.org/10.1186/s12872-018-0770-z)

Publication date:
2018

Licence:
CC BY

Document Version
Publisher's PDF, also known as Version of record

[Link to publication in Discovery Research Portal](#)

Citation for published version (APA):

Al-Talabany, S., Mordi, I., Houston, J. G., Colhoun, H. M., Weir-McCall, J. R., Matthew, S. Z., Looker, H. C., Levin, D., Belch, J. J. F., Dove, F., Khan, F., & Lang, C. C. (2018). Epicardial Adipose Tissue Is Related to Arterial Stiffness and Inflammation in Patients with Cardiovascular Disease and Type 2 Diabetes. *BMC Cardiovascular Disorders*, 18, 1-8. [31]. <https://doi.org/10.1186/s12872-018-0770-z>

General rights

Copyright and moral rights for the publications made accessible in Discovery Research Portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from Discovery Research Portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain.
- You may freely distribute the URL identifying the publication in the public portal.

Take down policy


If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

RESEARCH ARTICLE

Open Access



Epicardial adipose tissue is related to arterial stiffness and inflammation in patients with cardiovascular disease and type 2 diabetes

Shaween Al-Talabany^{1†}, Ify Mordi^{1*†} , J. Graeme Houston^{1,2†}, Helen M. Colhoun³, Jonathan R. Weir-McCall¹, Shona Z. Matthew¹, Helen C. Looker⁴, Daniel Levin¹, Jill J. F. Belch¹, Fiona Dove^{1,1}, Faisal Khan¹ and Chim C. Lang¹

Abstract

Background: Epicardial adipose tissue (EAT) is an emerging cardio-metabolic risk factor and has been shown to correlate with adverse cardiovascular (CV) outcome; however the underlying pathophysiology of this link is not well understood. The aim of this study was to evaluate the relationship between EAT and a comprehensive panel of cardiovascular risk biomarkers and pulse wave velocity (PWV) and indexed left ventricular mass (LVMI) in a cohort of patients with cardiovascular disease (CVD) and diabetes compared to controls.

Methods: One hundred forty-five participants (mean age 63.9 ± 8.1 years; 61% male) were evaluated. All patients underwent cardiovascular magnetic resonance (CMR) examination and PWV. EAT measurements from CMR were performed on the 4-chamber view. Blood samples were taken and a range of CV biomarkers was evaluated.

Results: EAT measurements were significantly higher in the groups with CVD, with or without T2DM compared to patients without CVD or T2DM (group 1 EAT 15.9 ± 5.5 cm² vs. group 4 EAT 11.8 ± 4.1 cm², $p = 0.001$; group 3 EAT 15.1 ± 4.3 cm² vs. group 4 EAT 11.8 ± 4.1 cm², $p = 0.024$). EAT was independently associated with IL-6 (beta 0.2, $p = 0.019$). When added to clinical variables, both EAT (beta 0.16, $p = 0.035$) and IL-6 (beta 0.26, $p = 0.003$) were independently associated with PWV. EAT was significantly associated with LVMI in a univariable analysis but not when added to significant clinical variables.

Conclusions: In patients with cardio-metabolic disease, EAT was independently associated with PWV. EAT may be associated with CVD risk due to an increase in systemic vascular inflammation. Whether targeting EAT may reduce inflammation and/or cardiovascular risk should be evaluated in prospective studies.

Keywords: Epicardial adipose tissue, Pulse wave velocity, Arterial stiffness, Cardiovascular magnetic resonance, Left ventricular mass, Type 2 diabetes mellitus

Background

The distribution of body fat appears to be important in cardiovascular disease (CVD) risk [1]. With recent advances in imaging techniques, attention has focussed on ectopic visceral fat distribution including the fat around the heart, known as epicardial adipose tissue (EAT). This

interest is underpinned by population cohort studies that reported the association between EAT and adverse CV outcome [2, 3]. EAT is a metabolically active visceral and perivascular fat depot, surrounding the myocardium and coronary arteries with no separating fascia. Under pathologic circumstances, EAT can act both locally or by paracrine secretion of mediators including adipokines, inflammatory cytokines, or reactive oxidative species that can potentially adversely affect the adjacent coronary vessels and myocardium [4]. Local secretion of bio-active molecules by the EAT has been implicated in the

* Correspondence: i.mordi@dundee.ac.uk

[†]Equal contributors

¹Division of Molecular and Clinical Medicine, University of Dundee, Mailbox 2, Ninewells Hospital & Medical School, Dundee DD1 9SY, UK
Full list of author information is available at the end of the article

formation of atherosclerotic plaques on the adjacent coronary arteries [5–8]. The local effects of these bioactive molecules on the neighbouring myocardium have also been linked to atrial remodelling in atrial fibrillation (AF) [9]. It is noteworthy that the effects of EAT on left ventricular remodelling such as left ventricular hypertrophy is less well studied.

Recent studies have shown that EAT is related to atherosclerotic disease in other vascular beds. In the population based Rotterdam Study, EAT was associated with multiple vessel beds and was independent of CV risk factors [10]. This observation may imply endocrine systemic effects of EAT [4]. EAT is metabolically active, secreting numerous substances associated with CVD such as TNF α , IL-6 and IL-1 β [11] that may suggest a systemic effect of EAT mediated via metabolic and inflammatory pathways. Exploring this link might help to provide a better understanding of the mechanism by which EAT is associated with CVD. Tentative supportive evidence of a systemic effect of EAT is provided by the association between EAT and arterial stiffness, a known predictor of adverse CV outcome [12]. Previous studies have demonstrated an independent association between EAT and arterial stiffness in various groups of patients with CVD risk [13, 14]. However, this relationship has not been studied in patients with cardio-metabolic disease and as yet the mechanism by which EAT and arterial stiffness are linked is poorly understood. The relationship between EAT and left ventricular hypertrophy in patients with cardio-metabolic disease has also not been studied.

The aim of this study was to assess the association between EAT, metabolic and inflammatory biomarkers, peripheral arterial stiffness (as measured by PWV) and left ventricular mass (LVM) in a cohort of patients with a spectrum of cardio-metabolic disease compared to controls to provide an understanding of the underlying local and systemic pathophysiological process by which EAT might lead to adverse CVD outcome.

Methods

Study participants

This study was a single centre observational cross sectional sub-study of the multicentre SUMMIT (SURrogate markers for Micro- and Macrovascular hard endpoints for Innovative diabetes Tools) study. Recruitment strategy and the imaging protocol have been described in detail previously [15]. In summary, 145 volunteers were recruited from the community, completed the imaging part of the SUMMIT study and were included for analysis in this study. These volunteers were categorised into one of four groups: Group 1 comprised of type 2 diabetes mellitus patients (T2DM) with clinical CVD including cerebrovascular disease, CAD and/or lower extremity arterial

disease (LEAD); Group 2 included volunteers with T2DM and no clinical evidence of CVD; Group 3 included subjects with clinical evidence of CVD and no T2DM; and Group 4 was a group in whom there was no clinical evidence of either T2DM or CVD. To be included in either of the T2DM groups there had to be a diagnosis of T2DM made after the age of 35 years with no requirement for insulin in the 12 months following the diagnosis. Absence of T2DM in Groups 3 and 4 was determined via testing of haemoglobin A1C (HbA1C) levels, and defined as a level of less than 6.5% (48 mmol/mol). Volunteers were excluded from the study if they had a contraindication to MRI, impaired renal function (eGFR < 30 ml/min/1.73m²), and therapy for any chronic inflammatory disease or malignancy. The study protocols were approved by The East of Scotland Research Ethics Committee, and were conducted in accordance with the Declaration of Helsinki. All volunteers who participated in this study provided written informed consent. Informed consent was obtained from each patient and the study protocol conformed to the ethical guidelines of the 1975 Declaration of Helsinki.

Cardiovascular magnetic resonance protocols

Cardiovascular magnetic resonance (CMR) images were acquired on a 32 RF receiver channel, 3.0 T Tesla MRI scanner (Magnetom Trio, Siemens, Erlangen, Germany). Full details of the CMR protocol and intra-observer reproducibility of LV analysis in this cohort have been as previously described in detail [15].

Epicardial adipose tissue quantification

EAT area was defined as the fat located between the outer wall of the myocardium and the visceral layer of the pericardium [16]. We chose a single cine four-chamber view of each patient for EAT quantification (in cm²) after a careful examination of the cine 4 chamber view image to outline the fat at the end-diastolic image as described in other studies [17–19]. EAT image analysis was carried out off-line using Segment (version 1.9, <http://segment.heiberg.se>) [20]. A representative example is shown in Fig. 1. Measurements were obtained using a TrueFISP electrocardiogram-gated cine four-chamber view during the end diastolic phase of the cardiac cycle and EAT was delineated using the freehand region of interest tool (Fig. 1). Measurement of EAT was performed with the analyser (SAT) blinded to both CVD and DM status. EAT was measured by two independent observers (SAT and JMW) in 20% of the studies ($n = 29$) selected at random to assess inter-observer variability.

Pulse wave velocity measurements

Arterial stiffness was assessed by calculating PWV using a Sphygmocor device (Atcor Medical, West Ryde, Australia) as described previously [21]. In brief, carotid-

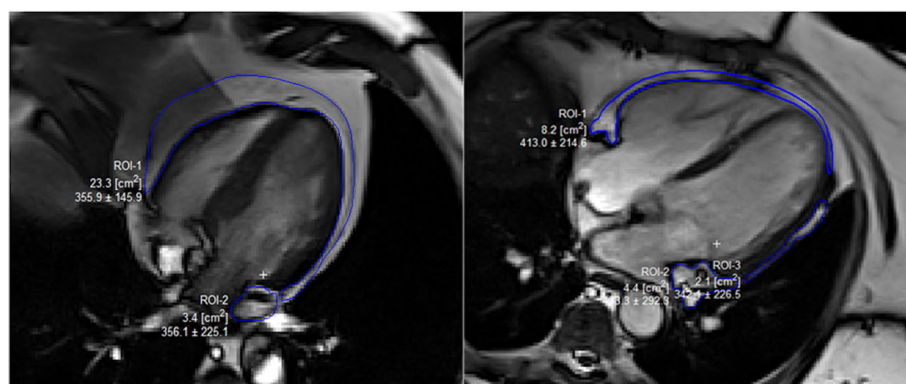


Fig. 1 Cardiovascular Magnetic Resonance Assessment of Epicardial Adipose Tissue. EAT was assessed on CMR cine images shown in this example. A – a patient in group 1 (type 2 diabetes and overt CV disease) with EAT measuring 26.7 cm². B – a patient in group 4 (no diabetes or overt CV disease) with EAT measuring 10.6 cm²

femoral PWV (measured in m/s) was calculated as the difference in time between the R wave of the ECG and the foot of the pulse curve at the carotid and femoral arteries, divided by the proximal distance (carotid to the fossa jugulars) subtracted from the distal distance (fossa jugulars to femoral artery measured via the umbilicus). Blood pressure was measured three times via a cuff attached to the left arm and the mean of the last two measurements recorded only after the patient relaxed for 5 min.

Biomarkers

Fifty-one biomarkers were analysed by the Proximity Extension Assay technique using the Proseek Multiplex CVD96*96 reagent kit (Olink Bioscience, Uppsala, Sweden) at the Clinical Biomarkers Facility, Science for Life Laboratory, Uppsala. The full list of biomarkers measured is shown in Additional file 1: Table S1.

Statistical analysis

All analyses were performed using SPSS (version 21.0, SPSS Inc. Chicago, IL, USA). Continuous variables are shown as mean \pm standard deviation. Categorical variables are reported as number with percentage in brackets. To compare the four groups, ANOVA was applied as a parametric test with post-hoc Bonferroni correction to account for multiple testing. In the investigation of associations among continuous variables, a Pearson correlation test was used for parametric data and a Spearman test for non-parametric data. Univariate and multivariable linear regressions were used for determining factors associated with EAT and PWV and LVM. Firstly, linear regression was performed to determine the association between biomarkers and EAT and PWV and LVM. Then, regression was performed to determine the independent association between clinical variables and EAT with PWV and LVM. Finally, biomarkers were added to the clinical variables and EAT to determine their association with PWV and LVM. To build

the multivariable models, significant baseline clinical variables were first included. Following this, EAT and significant biomarkers were added to significant clinical variables in order to build a final multivariable model for association with PWV and LVM. For all tests a $p < 0.05$ was considered statistically significant.

Results

Baseline characteristics

In total 145 participants were included in study. Full demographic details are shown in Table 1. Eighty-nine patients (61%) were male and the mean age of the whole cohort was 64.0 ± 8.1 years. Patients with DM had a significantly higher BMI, HDL cholesterol and HbA1c than those in group with neither DM nor CVD. CVD patients were significantly older than those without CVD. Patients without CVD or DM were significantly less likely to be male, have a history of hypertension, to be taking a statin and had a lower LDL-cholesterol than those in other groups. There was no significant difference in smoking prevalence or systolic blood pressure in all four groups. Patients with overt CVD were significantly more likely to be taking an ACE inhibitor and beta-blocker.

Relationship between epicardial adipose tissue, LV measurements and pulse wave velocity

PWV, EAT and LV measurements are presented in Table 1. Inter-observer variability for EAT was good (intra-class correlation coefficient of absolute agreement definition = 0.796). EAT measurements were significantly higher in the groups with CVD, with or without T2DM compared to patients without CVD or T2DM (group 1 EAT 15.9 ± 5.5 cm² vs. group 4 EAT 11.8 ± 4.1 cm², $p = 0.001$; group 3 EAT 15.1 ± 4.3 cm² vs. group 4 EAT 11.8 ± 4.1 cm², $p = 0.024$). A significant correlation was found between EAT and PWV ($r = 0.28$, $p = 0.002$). LVMI was also significantly higher in group 1 compared to group 4 (group 1 LVMI

Table 1 Baseline Demographics, Pulse Wave Velocity and Cardiovascular Magnetic Resonance Parameters

Variable	Group 1 CVD and DM (n = 34)	Group 2 No CVD with DM (n = 54)	Group 3 CVD without DM (n = 28)	Group 4 No CVD or DM (n = 29)	p value
Male	28 (82.4)* ^o	29 (53.7)	20 (71.4)	12 (41.4)	0.003
Age (years)	64.6 ± 6.6	62.4 ± 8.1+	67.6 ± 8.6	62.1 ± 8.0	0.022
BMI (kg/m ²)	31.0 ± 4.2*	31.0 ± 4.6*	29.2 ± 3.6	27.9 ± 3.7	0.007
Diabetes duration (years)	10.3 ± 4.8	9.0 ± 6.2	N/A	N/A	0.33
Current/Ex-smoker	25 (73.5)	27 (50.0)	16 (57.1)	15 (51.7)	0.16
Hypertension	27 (79.4)*	34 (63.0)*	24 (85.7)*	7 (24.1)	< 0.001
Stroke	5 (14.7)* ^o	0 (0)	2 (7.1)	0 (0)	0.008
LEAD	9 (26.5)* ^o	0 (0)	5 (17.9) ^o	0 (0)	< 0.001
CAD	25 (73.5)*	0 (0)	22 (78.6)* ^o	0 (0)	0.001
Atrial Fibrillation	1 (2.9)	1 (1.9)	1 (3.6)	2 (6.9)	0.69
ACE Inhibitor	21 (61.8)* ^o	17 (30.4)	15 (53.6)*	3 (10.3)	< 0.001
Beta Blocker	15 (44.1)* ^o	6 (11.1)	12 (42.9)* ^o	1 (3.4)	< 0.001
Statin	30 (88.2)*	39 (72.2)*	22 (78.6)*	7 (24.1)	< 0.001
Systolic BP (mmHg)	126.3 ± 12.5	134.0 ± 14.2	130.7 ± 13.6	132.7 ± 19.1	0.13
Diastolic BP (mmHg)	73.2 ± 7.1* ^o	78.0 ± 7.4	75.5 ± 8.5	81.0 ± 9.0	0.001
Total Cholesterol (mmol/l)	3.7 ± 0.8*	4.0 ± 0.8*	4.0 ± 0.7*	5.1 ± 0.9	< 0.001
LDL Cholesterol (mmol/l)	1.7 ± 0.5*	2.0 ± 0.8*	2.0 ± 0.6*	2.8 ± 0.8	< 0.001
HDL Cholesterol (mmol/l)	1.1 ± 0.3*	1.3 ± 0.3*	1.3 ± 0.5	1.5 ± 0.4	< 0.001
Triglycerides (mmol/l)	2.1 ± 1.0+	1.7 ± 0.8	1.5 ± 0.8	1.7 ± 1.0	0.06
Serum Creatinine (μmol/l)	84.4 ± 22.6* ^o	73.3 ± 17.3	82.5 ± 19.1	70.6 ± 15.3	0.006
HbA1c (mmol/l)	7.5 ± 1.1*+	7.2 ± 1.1*+	5.5 ± 0.2	5.6 ± 0.2	< 0.001
PWV (m/s)	11.4 ± 3.0	11.1 ± 2.7	11.1 ± 2.4	9.9 ± 2.4	0.12
EAT (cm ²)	15.9 ± 5.5*	13.5 ± 3.5	15.1 ± 4.3*	11.8 ± 4.1	0.001
LVMi (g/m ²)	61.7 ± 9.8*	55.5 ± 10.6	59.8 ± 10.0*	52.5 ± 8.4	0.001
LVEF (%)	64.6 ± 10.5	65.9 ± 8.9	64.6 ± 10.6	66.0 ± 7.4	0.86
LVEDVi (ml/m ²)	70.6 ± 12.4	67.0 ± 12.9+	75.5 ± 20.4	68.7 ± 9.9	0.07
LVESVi (ml/m ²)	25.4 ± 9.8	23.2 ± 9.0	28.0 ± 16.4	23.5 ± 6.7	0.24
LGE (%)	9 (26.5)	3 (5.6)	11 (39.3)	0 (0)	< 0.001

BMI body mass index; BP blood pressure; CAD coronary artery disease; LEAD lower extremity arterial disease; ACE angiotensin converting enzyme; ARB angiotensin II receptor blocker; PWV pulse wave velocity; LVM left ventricular mass index; LVEF left ventricular ejection fraction; LVEDV left ventricular end diastolic volume; LVESV left ventricular end systolic volume; SV stroke volume; LGE late gadolinium enhancement

Categorical data presented as number (percentage), continuous data presented as mean ± SD

*p < 0.05 vs. group 4 (no DM or CVD); +p < 0.05 vs. group 3 (CVD without DM); °p < 0.05 vs. group 2 (DM without CVD)

Figures in bold p < 0.05

61.7 ± 9.8 g/m² vs. group 4 LVMi 52.5 ± 8.4 g/m², p = 0.002). There was no significant difference in PWV amongst any of the four groups.

Relationship between epicardial adipose tissue and blood biomarkers

The full list of 51 CV biomarkers evaluated is reported in Additional file 1: Table S1. Of these biomarkers, we found two that were significantly correlated with both EAT and PWV in univariate analysis (CD40L and IL-6). There were no biomarkers that were significantly correlated with both EAT and LVM. In multivariable linear regression analysis of biomarkers, both IL-6 and CD40L remained significantly associated with PWV (IL-6: beta

0.26, p = 0.003) (CD40L: beta - 0.21 p = 0.014) (Table 2). In a univariate regression analysis, IL6 and CD40L were significantly associated with EAT (IL6: beta 0.2 p = 0.019; CD40L: beta - 0.21 p = 0.01) (Additional file 1:

Table 2 Multivariable Linear Regression of PWV and Biomarkers

	β	PWV (m/s)		p value
		95% CI	β (S)	
CD40L	-0.5	-0.90- -0.10	- 0.21	0.014
IL-6	0.67	0.23-0.1.12	0.26	0.003

PWV pulse wave velocity; CD40L CD40 ligand; IL-6 interleukin-6

All biomarkers significantly associated with EAT and PWV in univariate analysis (Additional file 1: Table S1) were included in multivariable analysis

Figures in bold p < 0.05

Figure S1). IL-6 was significantly higher in Group 1 compared to group 4 (group 1– 5.9 ± 1.3 pg/ml group 4– 4.8 ± 0.7 pg/ml $p < 0.001$).

Factors associated with pulse wave velocity

In univariate analysis for association with PWV we found that age, systolic blood pressure, history of smoking, lower extremity arterial disease, AF and EAT were all significantly associated with PWV (Additional file 1: Table S2). In a model with only significant clinical variables included, age (beta 0.32 $p < 0.001$), systolic BP (beta 0.34, $p < 0.001$) and lower extremity arterial disease (LEAD) (beta 0.17 $p = 0.025$) remained significantly associated with PWV (Table 3). When added to clinical variables, EAT remained associated with PWV (beta 0.12 $p = 0.026$). Finally, when IL-6 and CD40L were added to the model both EAT (beta 0.16 $p = 0.035$) and IL-6 (beta 0.20 $p = 0.005$) remained independently associated with PWV in addition to age and systolic blood pressure however CD40L was not. The stepwise additions of both EAT and IL-6 added significant independent power to model association with PWV.

Factors associated with left ventricular mass

In univariable analysis there were several significant clinical variables associated with LVMI, (Additional file 1: Table S2). EAT was also significantly associated with LVMI in univariate analysis (beta 0.33, $p = 0.002$). In multivariable analysis, only male gender and history of hypertension remained significantly associated with LVMI (Additional file 1: Table S3). When added to significant clinical variables EAT was no longer significantly associated with LVMI (beta 0.07, $p = 0.33$).

Discussion

In this study we identified several novel findings. First, we have shown that patients with overt cardio-metabolic disease have significantly more EAT than those without. Second, we have shown that EAT is significantly

associated with PWV, a marker of arterial stiffness that is linked to adverse CVD outcome. We did not, however, find any significant association between EAT and LVM. Finally, we have shown, to the best of our knowledge, for the first time, a clear association between EAT and IL-6, a biomarker associated with vascular inflammation, and that both EAT and IL-6 are significantly independently associated with PWV even when baseline clinical characteristics are accounted for and have incremental association PWV when added to clinical variables.

Arterial stiffness measured by PWV has been associated with an increased risk of CVD in a wide range of patients and has been found to be an independent predictor of major adverse CV events [12]. Furthermore, it has also been shown to have incremental additional prognostic value when used in combination with traditional risk predictors such as blood pressure and cholesterol [22]. Our finding that EAT is a significantly independently associated with arterial stiffness as measured by PWV is consistent with previous studies that showed that EAT, measured by echocardiography, was independently associated with endothelial function measured by PWV [23]. In a study of 100 patients with biopsy-proven non-alcoholic fatty liver disease (NAFLD), a condition associated with inflammation and atherosclerosis, the authors found that epicardial adipose thickness was significantly higher NAFLD patients compared to controls and was a significant independent predictor of PWV [24]. Our study extends the results of this study to patients with cardio-metabolic disease by assessing patients with CMR (the gold-standard). In our study, the availability of a comprehensive panel of biomarkers may help provide a mechanistic understanding for these observations.

Prior studies have demonstrated that inflammation, oxidative stress, and visceral fat volume predispose to CVD [1, 25]. There have been several studies examining the link between pericardial adipose and CVD. In a study of over 6000 patients from the MESA cohort the authors found

Table 3 Multivariable associations with pulse wave velocity

	Clinical				Clinical + EAT				Clinical + EAT + Biomarkers			
	β	95% CI	β (S)	p value	β	95% CI	β (S)	p value	β	95% CI	β (S)	p value
Age	0.11	0.07–0.16	0.36	< 0.001	0.10	0.06–0.15	0.32	< 0.001	0.10	0.05–0.15	0.31	< 0.001
Systolic BP	0.06	0.04–0.09	0.37	< 0.001	0.07	0.04–0.09	0.37	< 0.001	0.07	0.04–0.09	0.39	< 0.001
LEAD	1.60	0.21–2.98	0.17	0.025	1.47	0.11–2.84	0.15	0.035	1.30	–0.04–2.65	0.14	0.06
Atrial fibrillation	2.03	–0.11–4.16	0.14	0.06								
EAT					0.10	0.01–0.19	0.17	0.026	0.10	0.01–0.19	0.16	0.03
IL-6									0.53	0.16–0.90	0.20	0.005
CD40L									–0.03	–0.37–0.31	–0.01	0.86
Chi-Square	0.613				0.634*				0.658^			

BP blood pressure; LEAD lower extremity arterial disease; EAT epicardial adipose tissue; IL-6 interleukin 6, CD40L CD40 ligand, (S) standardized

* p 0.026 vs. clinical; ^ p = 0.011 vs. clinical + EAT

Figures in bold $p < 0.05$

that pericardial adipose volume had a significant positive association with IL-6, and also had a borderline significance for CVD outcomes after adjustment for traditional risk factors [26]. More specifically, pericardial adipose also predicted incident coronary heart disease in a subset of these patients [27]. Finally, in a large cohort of over 1000 patients from the Framingham study, Tadros et al. reported an association between pericardial fat and inflammatory biomarkers including IL-6 [28].

More recent work has suggested that EAT is associated with systemic inflammation. A meta-analysis of 40 gene expression studies on EAT suggested that EAT might well mediate its effects on CVD through IL6 [29]. These observations lend support to the increasing recognition that EAT is a metabolically active endocrine organ and a source of pro-inflammatory adipokines that have significant impact on remote vascular tissues [30]. The findings of our study lend support to this. In our study IL-6, an inflammation mediator, was strongly associated with both EAT and with PWV. It is noteworthy that IL-6 is capable of inducing vascular smooth muscle proliferation that can lead to endothelial dysfunction and arterial stiffness [31]. In our study, we observed an incremental independent association of both EAT and IL-6 with PWV shown, for the first time, in our study. Indeed, further supporting our inflammatory theory is the association with CD40L, although this did not remain significant when included in the multivariable model. CD40L has also been associated with cardio-metabolic disease and is known to be released by adipose tissue [32, 33]. Obviously, any indication that the observed relationship between EAT and PWV are due to the effects of IL-6 remains purely speculative and cannot be inferred directly from this observational study. Additionally, the fact that EAT was still independently associated with PWV even when IL-6 was added to the model might suggest that there may be other pathways which need to be further elucidated by which EAT is associated with increased PWV.

In our study we found that although EAT was associated with LVM in a univariate analysis, it was not significant in multivariable analysis. Prior studies using echocardiography have reported differing results regarding the relationship between EAT and LVM. Fosshaug et al. evaluated 60 heart failure patients and found that EAT was related to LVM [34]. These results were replicated in a more recent study using PET-CT by Bakkum et al. in over 200 obese patients without significant CAD [35]. Both of these studies contrast the study by Gates et al. in 119 healthy males suggesting that overall body fat was linked to LVM rather than EAT [36]. Our study differs from all of these studies by using CMR, the gold-standard for assessment of LVMI. Additionally, our study is also, to the best of our knowledge, the first to include patients with CVD and T2D disease rather than just healthy volunteers. Because of this, there may however have been confounding of

LVM based on medication use such as ACE inhibitors. It may however be the case that LVM is not influenced by local adipose but rather by overall adiposity and BMI. A large study from the Framingham cohort found that while pericardial adipose was associated with LVM in univariable analysis, this association was no longer significant once adjusted for body weight or visceral adipose [37].

Limitations

As our findings come from a single-center study, these findings require confirmation within a larger multi-center setting. Due to the nature of recruitment of these patients in which the full biomarker panel was only available in a single centre, the number of patients for analysis is relatively small, although this is one of the largest papers to examine EAT, PWV and such a comprehensive panel of biomarkers using CMR. Additionally as a cross-sectional study causality cannot be proven and only associations can be made. Although we feel that our selection of 51 biomarkers is both pragmatic and broadly covers most pathophysiologically important biomarkers, we cannot completely exclude the possibility that there may be other biomarkers which could be important, for example adiponectin. Finally, we only performed measurement of EAT in the 4-chamber view. Theoretically 3-dimensional measurement of EAT may have provided different results, however we wished to perform a protocol that was simple to utilise and not too time-consuming for practicing clinicians. However, measurement of adipose in the 4-chamber view has shown excellent correlation with 3-dimensional quantification in several other studies [17–19]. Despite these limitations, we believe our findings are of potential importance and can be seen as hypothesis-generating.

Conclusions

EAT is gaining prominence as a non-invasive biomarker which might be associated with adverse CV outcome, however the mechanism by which it does so remains unclear. We performed a study in patients in both controls and patients with type 2 diabetes and/or overt cardiovascular disease evaluating EAT measured by CMR and examined its relations with established CV biomarkers, arterial stiffness measured by PWV and left ventricular mass. EAT was significantly increased in patients with overt cardio-metabolic disease compared to those without and was independently associated with arterial stiffness measured by pulse wave velocity. EAT was significantly associated with increased markers of systemic inflammation (IL-6) and both EAT and IL-6 were significantly associated with PWV independent of clinical variables, suggesting potential inflammatory pathophysiological link. Additionally, both EAT and IL-6 had significant incremental association with PWV. EAT may be associated with systemic inflammation and could be a therapeutic target in cardio-metabolic disease.

Additional file

Additional file 1: Table S1. Correlations between cardiovascular biomarkers and epicardial adipose tissue (EAT), pulse wave velocity (PWV) and left ventricular mass index (LVMI). **Table S2.** Univariable Linear Regression of Clinical Variables and EAT with Pulse Wave Velocity and LV Mass Index. **Table S3.** Multivariable Associations with LV Mass Index. **Figure S1.** Correlations between EAT, IL-6 and CD40L. (DOCX 88 kb)

Abbreviations

AF: Atrial fibrillation; CVD: Cardiovascular disease; EAT: Epicardial adipose tissue; LEAD: Lower extremity arterial disease; LV: Left ventricular; LVM: Left ventricular mass; LVMI: Left ventricular mass index; PWV: Pulse wave velocity; T2DM: Type 2 diabetes mellitus

Acknowledgements

Deidre Cassidy is acknowledged for her support and direction in regards to the method of EAT measurement protocol.

Funding

This is sub-study of the multicentre SUMMIT study. The research leading to these results has received support from the Innovative Medicines Initiative Joint Undertaking under Grant Agreement No. 115006, resources of which are composed of financial contribution from the European Union's Seventh Framework Programme (FP7/2007–2013) and EFPIA companies in kind contribution. IM is supported by a NHS Education for Scotland/Chief Scientist Office Postdoctoral Clinical Lectureship (PCL 17/07). JRWM is supported by the Wellcome Trust through the Scottish Translational Medicine and Therapeutics Initiative (Grant No. WT 085664) in the form of a Clinical Research Fellowship. Neither groups had any role in: study design, the collection, analysis, and interpretation of data; in the writing of the manuscript; nor in the decision to submit the manuscript for publication.

Availability of data and materials

The datasets generated and/or analysed during the current study are not publicly available as they are part of a larger study but are available from the corresponding author on reasonable request.

Authors' contributions

SAT, IM, CCL, FK, HMC, JGH conceived the study. SAT, JRWM analysed the MRI studies. SAT, IM, DL, SZM, HCL, FD and JRWM analysed and interpreted the data. JRWM and JGH worked on the development of the MRI protocol. SAT and IM drafted the manuscript. All authors revised the manuscript critically for important intellectual content. All authors read and approved the final manuscript. All authors take responsibility for all aspects of the reliability and freedom from bias of the data presented and their discussed interpretation. There are no conflicts of interest.

Ethics approval and consent to participate

The study protocols were approved by The East of Scotland Research Ethics Committee, and were conducted in accordance with the Declaration of Helsinki. All volunteers who participated in this study provided written informed consent. Informed consent was obtained from each patient and the study protocol conformed to the ethical guidelines of the 1975 Declaration of Helsinki.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Author details

¹Division of Molecular and Clinical Medicine, University of Dundee, Mailbox 2, Ninewells Hospital & Medical School, Dundee DD1 9SY, UK. ²NHS Tayside

Clinical Radiology, Ninewells Hospital, Dundee DD1 9SY, UK. ³Institute of Genetics and Molecular Medicine, University of Edinburgh, Edinburgh EH4 2XU, UK. ⁴Dundee Epidemiological and Biostatistics Unit, University of Dundee, Dundee DD1 9SY, UK.

Received: 12 October 2017 Accepted: 2 February 2018

Published online: 13 February 2018

References

- Despres JP. Body fat distribution and risk of cardiovascular disease: an update. *Circulation*. 2012;126(10):1301–13.
- Britton KA, Massaro JM, Murabito JM, Kregar BE, Hoffmann U, Fox CS. Body fat distribution, incident cardiovascular disease, cancer, and all-cause mortality. *J Am Coll Cardiol*. 2013;62(10):921–5.
- Mahabadi AA, Berg MH, Lehmann N, Kalsch H, Bauer M, Kara K, Dragano N, Moebus S, Jockel KH, Erbel R, et al. Association of epicardial fat with cardiovascular risk factors and incident myocardial infarction in the general population: the Heinz Nixdorf Recall Study. *J Am Coll Cardiol*. 2013;61(13):1388–95.
- Iacobellis G. Local and systemic effects of the multifaceted epicardial adipose tissue depot. *Nat Rev Endocrinol*. 2015;11(6):363–71.
- Karastergiou K, Evans I, Ogston N, Miheisi N, Nair D, Kaski JC, Jahangiri M, Mohamed-Ali V. Epicardial adipokines in obesity and coronary artery disease induce atherogenic changes in monocytes and endothelial cells. *Arterioscler Thromb Vasc Biol*. 2010;30(7):1340–6.
- Shimabukuro M, Hirata Y, Tabata M, Dagvasumberel M, Sato H, Kurobe H, Fukuda D, Soeki T, Kitagawa T, Takanashi S, et al. Epicardial adipose tissue volume and adipocytokine imbalance are strongly linked to human coronary atherosclerosis. *Arterioscler Thromb Vasc Biol*. 2013;33(5):1077–84.
- Mazurek T, Zhang L, Zalewski A, Mannion JD, Diehl JT, Arafat H, Sarov-Blat L, O'Brien S, Keiper EA, Johnson AG, et al. Human epicardial adipose tissue is a source of inflammatory mediators. *Circulation*. 2003;108(20):2460–6.
- Baker AR, Silva NF, Quinn DW, Harte AL, Pagano D, Bonser RS, Kumar S, McTernan PG. Human epicardial adipose tissue expresses a pathogenic profile of adipocytokines in patients with cardiovascular disease. *Cardiovasc Diabetol*. 2006;5:1.
- Hatem SN, Redheuil A, Gandjbakhch E. Cardiac adipose tissue and atrial fibrillation: the perils of adiposity. *Cardiovasc Res*. 2016;109(4):502–9.
- Bos D, Shahzad R, van Walsum T, van Vliet LJ, Franco OH, Hofman A, Niessen WJ, Vernooij MW, van der Lugt A. Epicardial fat volume is related to atherosclerotic calcification in multiple vessel beds. *Eur Heart J Cardiovasc Imaging*. 2015;16(11):1264–9.
- Iacobellis G, Bianco AC. Epicardial adipose tissue: emerging physiological, pathophysiological and clinical features. *Trends Endocrinol Metab*. 2011;22(11):450–7.
- Willum-Hansen T, Staessen JA, Torp-Pedersen C, Rasmussen S, Thijs L, Ibsen H, Jeppesen J. Prognostic value of aortic pulse wave velocity as index of arterial stiffness in the general population. *Circulation*. 2006;113(5):664–70.
- Choi TY, Ahmadi N, Sourayanezhad S, Zeb I, Budoff MJ. Relation of vascular stiffness with epicardial and pericardial adipose tissues, and coronary atherosclerosis. *Atherosclerosis*. 2013;229(1):118–23.
- Natale F, Tedesco MA, Mocerino R, de Simone V, Di Marco GM, Aronne L, Credendino M, Siniscalchi C, Calabro P, Cotrufo M, et al. Visceral adiposity and arterial stiffness: echocardiographic epicardial fat thickness reflects, better than waist circumference, carotid arterial stiffness in a large population of hypertensives. *Eur J Echocardiogr*. 2009;10(4):549–55.
- Duce SL, Weir-McCall JR, Gandy SJ, Matthew SZ, Cassidy DB, McCormick L, Rauchhaus P, Looker H, Colhoun HM, Houston JG. Cohort comparison study of cardiac disease and atherosclerotic burden in type 2 diabetic adults using whole body cardiovascular magnetic resonance imaging. *Cardiovasc Diabetol*. 2015;14:122.
- Kessels K, Cramer MJ, Velthuis B. Epicardial adipose tissue imaged by magnetic resonance imaging: an important risk marker of cardiovascular disease. *Heart*. 2006;92(7):962.
- Graner M, Nyman K, Siren R, Pentikainen MO, Lundbom J, Hakkarainen A, Lauerma K, Lundbom N, Nieminen MS, Taskinen MR. Ectopic fat depots and left ventricular function in nondiabetic men with nonalcoholic fatty liver disease. *Circ Cardiovasc Imaging*. 2015;8(1):7–14.
- Graner M, Siren R, Nyman K, Lundbom J, Hakkarainen A, Pentikainen MO, Lauerma K, Lundbom N, Adiels M, Nieminen MS, et al. Cardiac steatosis

- associates with visceral obesity in nondiabetic obese men. *J Clin Endocrinol Metab.* 2013;98(3):1189–97.
19. Nyman K, Graner M, Pentikainen MO, Lundbom J, Hakkarainen A, Siren R, Nieminen MS, Taskinen MR, Lundbom N, Lauerma K. Cardiac steatosis and left ventricular function in men with metabolic syndrome. *J Cardiovasc Magn Reson.* 2013;15:103.
 20. Heiberg E, Sjogren J, Ugander M, Carlsson M, Engblom H, Arheden H. Design and validation of segment–freely available software for cardiovascular image analysis. *BMC Med Imaging.* 2010;10:1.
 21. Shore AC, Colhoun HM, Natali A, Palombo C, Ostling G, Aizawa K, Kennback C, Casanova F, Persson M, Gooding K, et al. Measures of atherosclerotic burden are associated with clinically manifest cardiovascular disease in type 2 diabetes: a European cross-sectional study. *J Intern Med.* 2015;278(3):291–302.
 22. Mattace-Raso FU, van der Cammen TJ, Hofman A, van Popele NM, Bos ML, Schalekamp MA, Asmar R, Reneman RS, Hoeks AP, Breteler MM, et al. Arterial stiffness and risk of coronary heart disease and stroke: the Rotterdam study. *Circulation.* 2006;113(5):657–63.
 23. Kim BJ, Kim BS, Kang JH. Echocardiographic epicardial fat thickness is associated with arterial stiffness. *Int J Cardiol.* 2013;167(5):2234–8.
 24. Sunbul M, Agirbasli M, Durmus E, Kivrak T, Akin H, Aydin Y, Ergelen R, Yilmaz Y. Arterial stiffness in patients with non-alcoholic fatty liver disease is related to fibrosis stage and epicardial adipose tissue thickness. *Atherosclerosis.* 2014;237(2):490–3.
 25. Willerson JT, Ridker PM. Inflammation as a cardiovascular risk factor. *Circulation.* 2004;109(21 Suppl 1):II2–10.
 26. Ong KL, Ding J, McClelland RL, Cheung BM, Ciriak MH, Barter PJ, Rye KA, Allison MA. Relationship of pericardial fat with biomarkers of inflammation and hemostasis, and cardiovascular disease: the multi-ethnic study of atherosclerosis. *Atherosclerosis.* 2015;239(2):386–92.
 27. Ding J, Hsu FC, Harris TB, Liu Y, Kritchevsky SB, Szklo M, Ouyang P, Espeland MA, Lohman KK, Ciriak MH, et al. The association of pericardial fat with incident coronary heart disease: the multi-ethnic study of atherosclerosis (MESA). *Am J Clin Nutr.* 2009;90(3):499–504.
 28. Tadros TM, Massaro JM, Rosito GA, Hoffmann U, Vasan RS, Larson MG, Keane JF Jr, Lipinska I, Meigs JB, Kathiresan S, et al. Pericardial fat volume correlates with inflammatory markers: the Framingham heart study. *Obesity (Silver Spring).* 2010;18(5):1039–45.
 29. Maghbooli Z, Hossein-Nezhad A. Transcriptome and molecular endocrinology aspects of Epicardial adipose tissue in cardiovascular diseases: a systematic review and meta-analysis of observational studies. *Biomed Res Int.* 2015;2015:926567.
 30. Salazar J, Luzardo E, Mejias JC, Rojas J, Ferreira A, Rivas-Rios JR, Bermudez V. Epicardial fat: physiological, pathological, and therapeutic implications. *Cardiol Res Pract.* 2016;2016:1291537.
 31. Klouche M, Bhakdi S, Hemmes M, Rose-John S. Novel path to activation of vascular smooth muscle cells: up-regulation of gp130 creates an autocrine activation loop by IL-6 and its soluble receptor. *J Immunol.* 1999;163(8):4583–9.
 32. Wolf D, Jehle F, Michel NA, Bukosza EN, Rivera J, Chen YC, Hoppe N, Dufner B, Rodriguez AO, Colberg C, et al. Coinhibitory suppression of T cell activation by CD40 protects against obesity and adipose tissue inflammation in mice. *Circulation.* 2014;129(23):2414–25.
 33. Missiou A, Wolf D, Platzer I, Ernst S, Walter C, Rudolf P, Zirlik K, Kostlin N, Willecke FK, Munkel C, et al. CD40L induces inflammation and adipogenesis in adipose cells—a potential link between metabolic and cardiovascular disease. *Thromb Haemost.* 2010;103(4):788–96.
 34. Fosshaug LE, Dahl CP, Risnes I, Bohov P, Berge RK, Nymo S, Geiran O, Yndestad A, Gullestad L, Aukrust P, et al. Altered levels of fatty acids and inflammatory and metabolic mediators in Epicardial adipose tissue in patients with systolic heart failure. *J Card Fail.* 2015;21(11):916–23.
 35. Bakum MJ, Danad I, Romijn MA, Stuijzand WJ, Leonora RM, Tulevski II, Somsen GA, Lammertsma AA, van Kuijk C, van Rossum AC, et al. The impact of obesity on the relationship between epicardial adipose tissue, left ventricular mass and coronary microvascular function. *Eur J Nucl Med Mol Imaging.* 2015;42(10):1562–73.
 36. Gates PE, Gentile CL, Seals DR, Christou DD. Adiposity contributes to differences in left ventricular structure and diastolic function with age in healthy men. *J Clin Endocrinol Metab.* 2003;88(10):4884–90.
 37. Fox CS, Gona P, Hoffmann U, Porter SA, Salton CJ, Massaro JM, Levy D, Larson MG, D'Agostino RB Sr, O'Donnell CJ, et al. Pericardial fat, intrathoracic fat, and measures of left ventricular structure and function: the Framingham heart study. *Circulation.* 2009;119(12):1586–91.

Submit your next manuscript to BioMed Central and we will help you at every step:

- We accept pre-submission inquiries
- Our selector tool helps you to find the most relevant journal
- We provide round the clock customer support
- Convenient online submission
- Thorough peer review
- Inclusion in PubMed and all major indexing services
- Maximum visibility for your research

Submit your manuscript at
www.biomedcentral.com/submit

